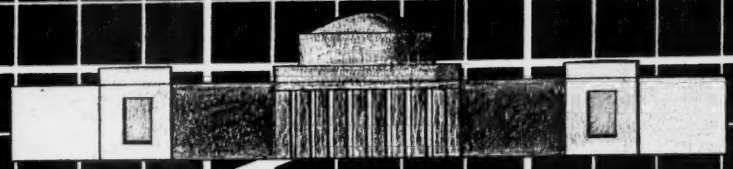

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the tech engineering news

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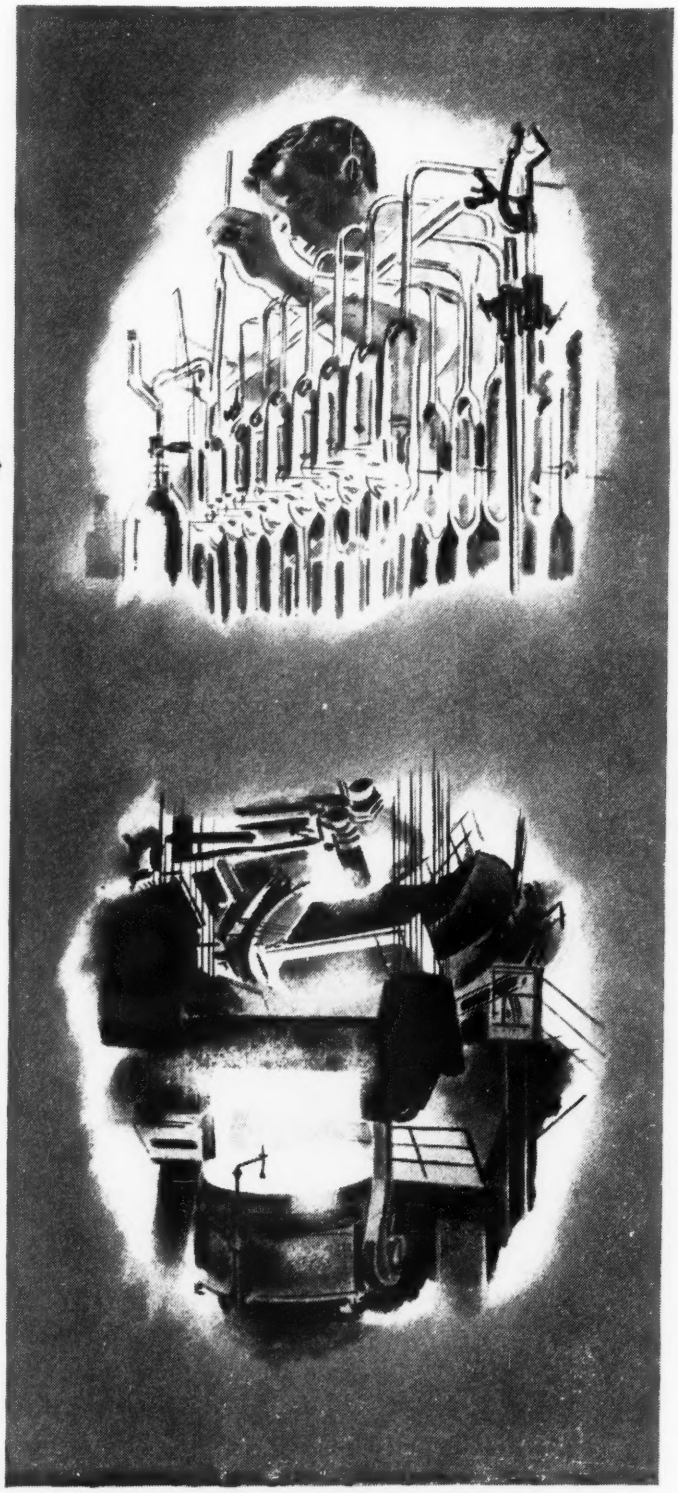

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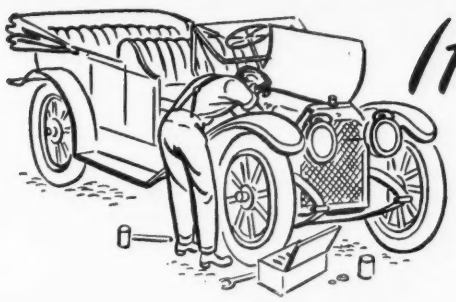

It's springtime 256 times a second

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—National Tube Company develops revolutionary new mill design

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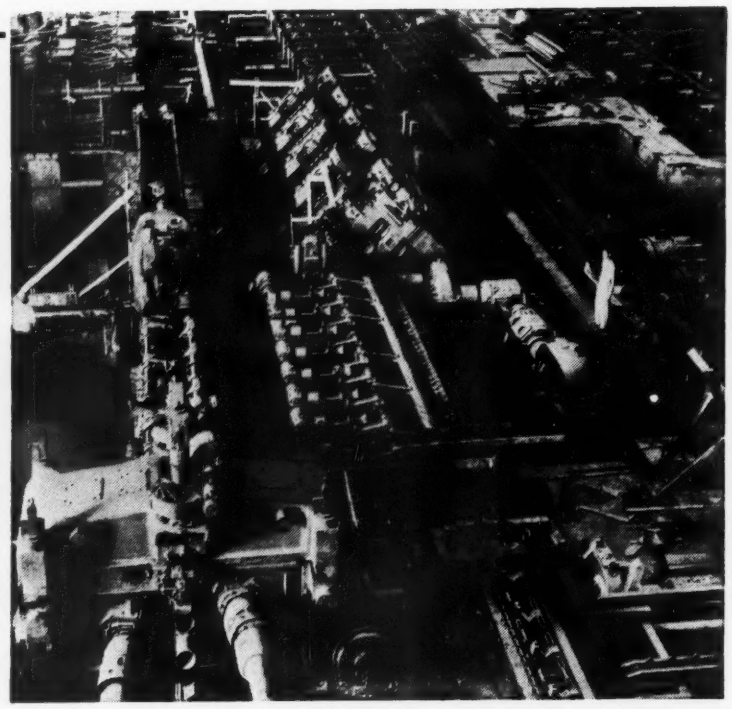
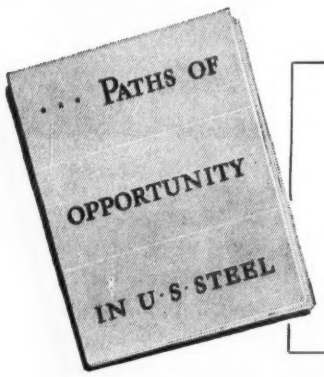
This revolutionary seamless mill design is another demonstration of National Tube Company's position of leadership in providing industry with both quality and quantity products.



Construction view showing 9-stand Rolling Mill and Inlet and Outlet Conveyors.



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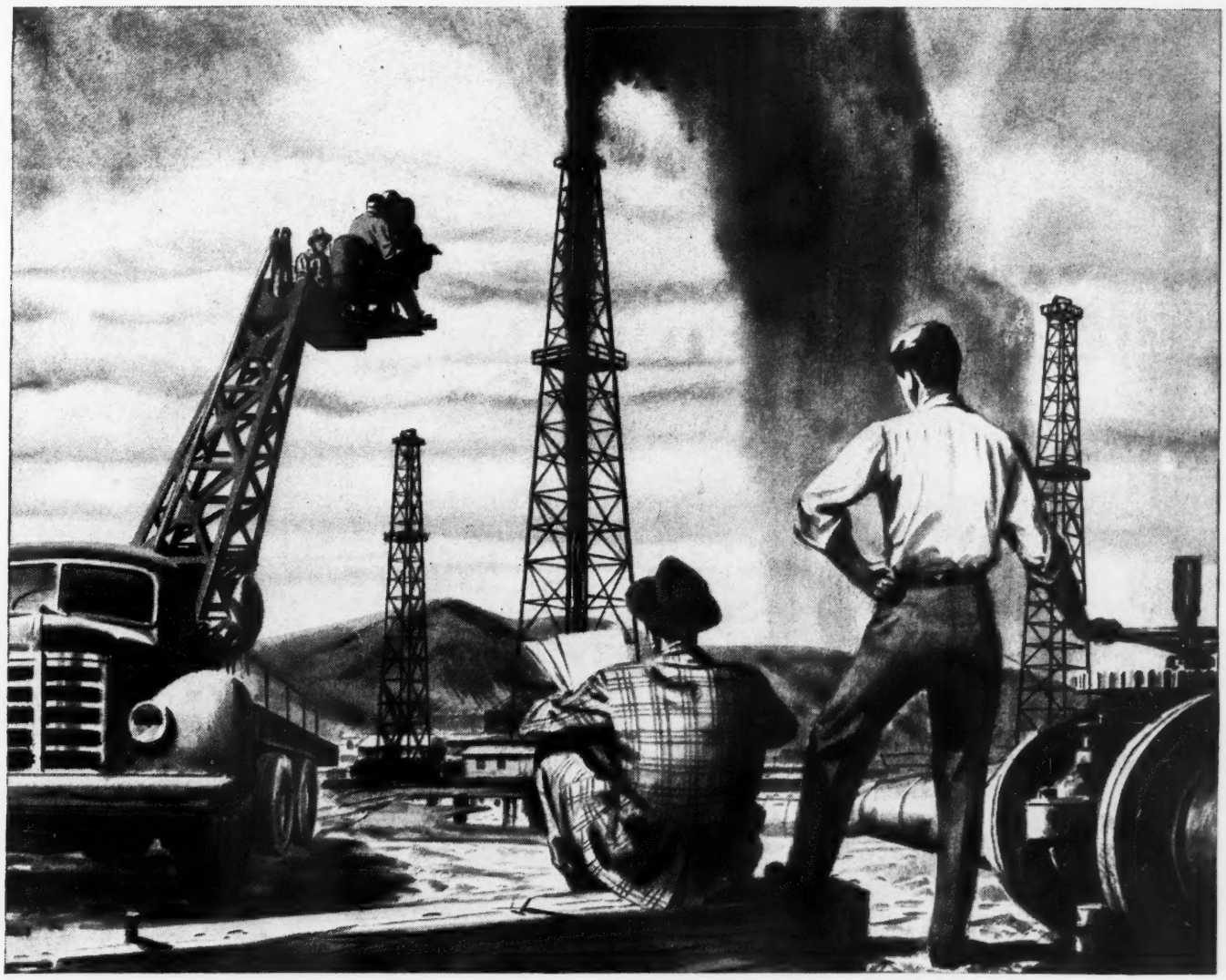

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CHEMICALS INDISPENSABLE TO INDUSTRY AND AGRICULTURE

the tech engineering news

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MEMBER OF THE ENGINEERING COLLEGE MAGAZINES ASSOCIATED

Published monthly during the school year at Walker Memorial, Cambridge 39, Massachusetts, by the undergraduates of the Massachusetts Institute of Technology. Entered as second class matter, at the Post Office, June 1, 1920, at Boston, Massachusetts under the Act of March 3, 1879. Copyright 1948 by The Tech Engineering News. Subscription per year $1.50. Foreign $2.25. One copy 25 cents.

shooting stars

By George B. Field, '51

Tools for Research on the Upper Atmosphere

The earth's atmosphere can be conveniently divided into three regions: the troposphere, extending from sea level to a height of about eleven kilometers; the stratosphere, occupying a region from eleven to thirty kilometers in height; and the upper atmosphere, which consists of all the air above thirty kilometers. The upper limit of the latter region, the height above which there is *no* air, has been given in the neighborhood of eight hundred kilometers; a more meaningful statement, however, is that only two per cent of the air mass lies above a height of thirty kilometers.

The troposphere is naturally the field for meteorological study, for it is here that the weather is generated: One finds turbulent air currents and cloud formations in the troposphere alone.

In addition to these salient features of weather, meteorologists study more subtle pressure and temperature variations in the atmosphere with the aid of balloon and airplane ascents, and more recently with radio-equipped sounding balloons. However, the best flights by these devices are rarely higher than forty kilometers.

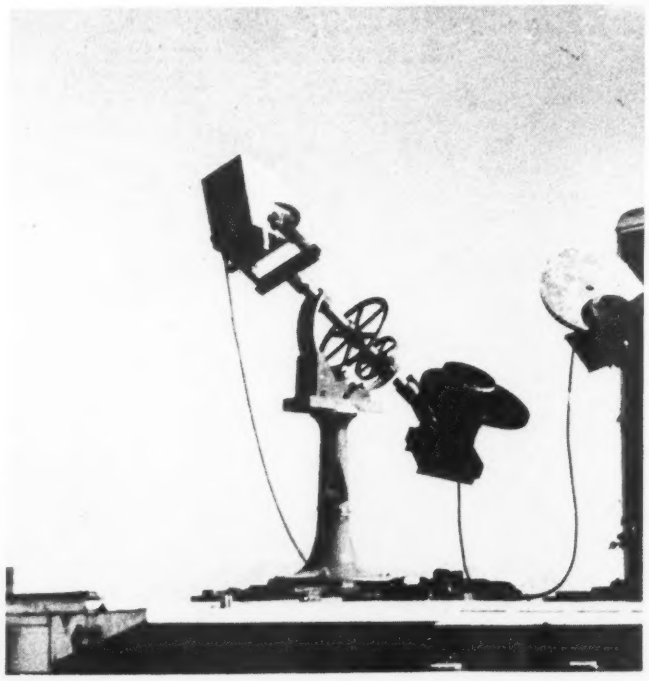
The stratosphere and upper atmosphere comprise a calm sea of thin air, which is the scene of many phenomena of primary interest: radio-beam reflection. cosmic rays, and the aurora borealis. Furthermore, it seems likely that trajectories of future high-soaring jets and rockets will extend into this region.

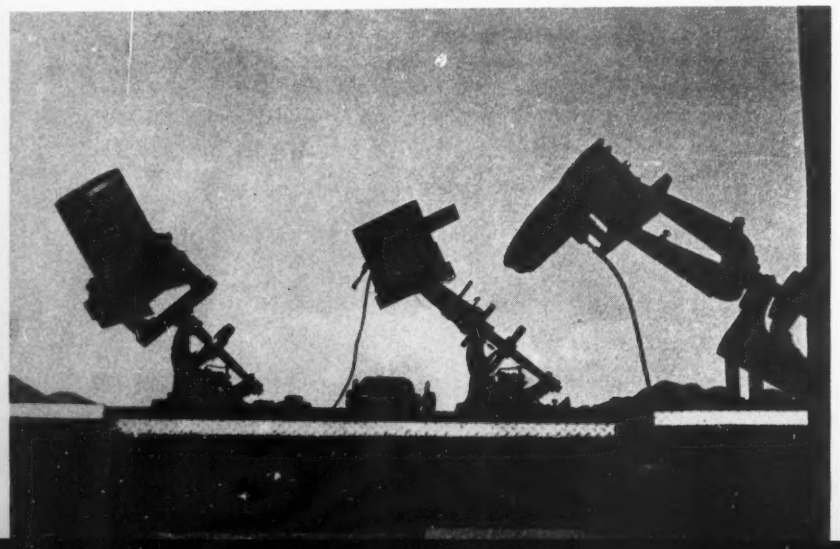
These facts have given impetus to the investigation of the upper atmosphere as an air mass, for certainly any intensive or extensive properties which can be discovered about the air in this region will have direct bearing on problems in these fields. But, in the face of limitations on balloon ascents, how can the upper atmosphere be studied?

To this question has been given an ingenious answer — the study of the flight of meteors through the upper atmosphere. Work utilizing this method is now being carried on jointly by the Harvard College Observatory and the M. I. T. Center of Analysis, under the sponsorship of the United States Navy. This method is particularly effective for the study of the atmosphere between one hundred and sixty kilometers, for meteors usually appear and burn out between these respective heights.

The mechanics of meteor motion is rather complex. Meteors enter the atmosphere with velocities between twelve and seventy-two kilometers per second. Air resistance, or drag, causes them to heat up and finally melt. The melted and brightly glowing matter is swept away by the rushing air. So, in effect, the problem is one of a variable mass moving through a viscous fluid. Though these complications might seem insurmountable, it is just these facts that make it possible to deduce properties of the air by the flight of the meteor, as we shall see.

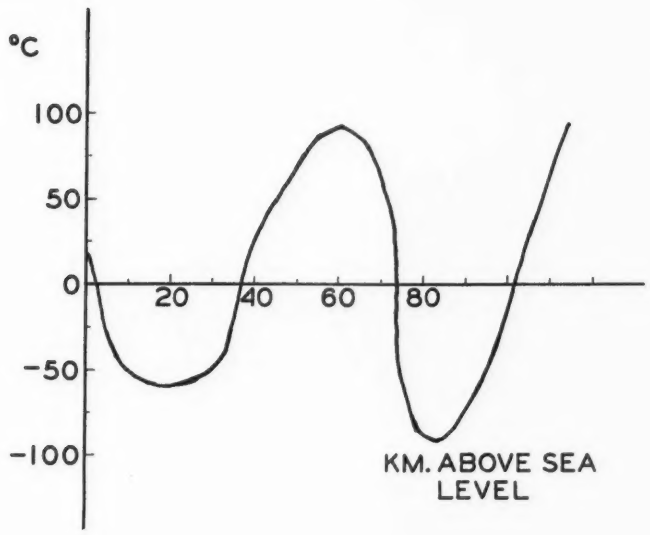
The work is divided into two distinct operations: photographing meteor trails, and analyzing them mathematically. The photography is done by Harvard's Cambridge and Oak Ridge Observatories. Located thirty kilometers apart at Cambridge and Harvard, Massachusetts, respectively, these two observatories train two specially built cameras at a point eighty kilometers above the earth, an average height for meteor trails. When a meteor passes near this point it is recorded as a streak of light by both cameras. The laws of chance decree that the number of meteors photographed this way be quite small; four or five a year is considered a good yield! But even at that, this arrangement represents tremendous improvement over chance reports by unskilled observers. The unique





The special meteor cameras which were used to gather information on atmospheric conditions are here shown on their way to their permanent location at Alamagordo, New Mexico. Note shutter devices projecting from side of cameras.

Atmospheric temperature does not vary regularly with height, as this graph shows. The approximately level stretch between eleven and twenty kilometers is known as the stratosphere and was originally thought to be isothermal.



construction of the camera records the meteor trail not as a solid line, but one broken periodically. This is accomplished by a shutter which rotates twenty times per second. The whole system, like a fisherman's net cast in the sea, lies in wait for the catch that is sure to come. When the meteor does arrive, it is recorded automatically by the two stations as a series of streaks on a plate. The scientists have already evolved an improvement on this system. A new camera, of twelve-inch diameter, and two-thirds focal ratio, is planned. Designed by the Perkin Elmer Corporation, this camera will have a shutter speed of one hundredth of a second, and should record as many as one hundred meteors per year with much greater accuracy.

Once the meteor has been photographed, the two plates which record its brief flight through space are subjected to a rigorous mathematical analysis at M. I.T. This work is carried on by the Center of Analysis under the direction of Dr. Zdenek Kopal and Dr. L. Jacchia. At the Center there is every facility for computation, both automatic and manual, but it has been found that the variety of problems to be solved is more efficiently handled by a corps of skilled computers than by the well-known Differential Analyzer.

When a set of plates is received, they are placed on the measuring machine, which is essentially an adjustable flat plate equipped with a crosshair viewer. This machine, which cost $6,000, was manufactured with the greatest precision by D. W. Mann of Lincoln, Massachusetts. Half the cost is represented by a screw ten inches in length, so fine that it can be adjusted within an accuracy of one-tenth of a micron! This distance corresponds to a length of only one-tenth of a meter in the actual path of the meteor.

There is a rectangular system of coordinates, say x and y, in the plane of the plate. By adjusting the position of the plae so that a point to be measured lies under the crosshair of the viewer, the operator can read values for x and y on adjoining scales. This is done by each of four observers, to minimize personal errors.

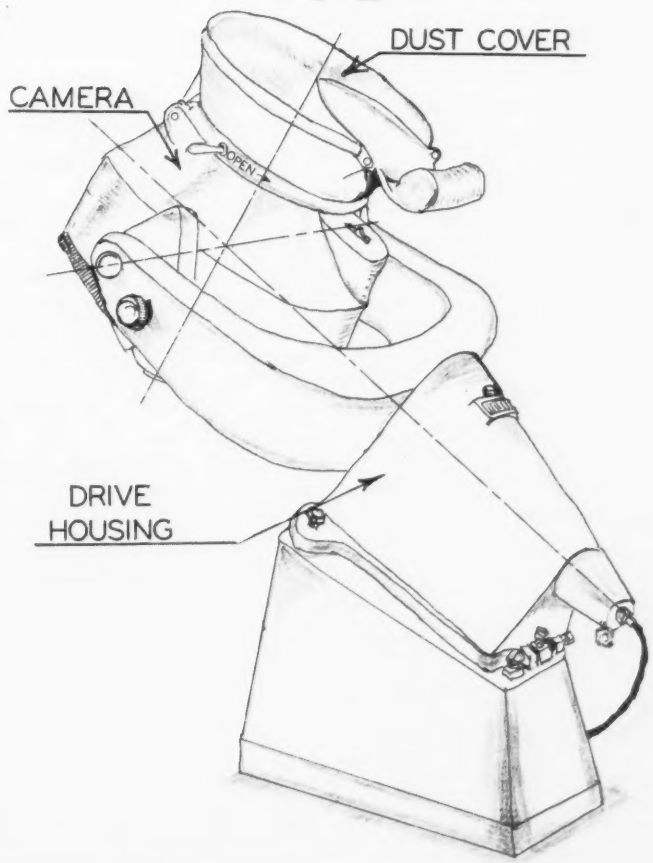
The object of the above procedure is to determine the actual path of the meteor through space. Values of x and y are obtained for many points on the path, and also for some recognizable stars on the plate. Since the positions of these stars are already known in celestial coordinates, it is possible to find constants by which the values of x and y on the plate can be converted to celestial coordinates. One fact which must be known, however, before this can be done, is the sidereal time at which the plate was made. To find this one notes the projection on the celestial sphere of the same point on the trail (such as a flare) as seen from the two stations. Because there is a unique time at which projections will have given positions, the time can be readily deduced. By triangulation the path of the meteor, including its height at every point, can be derived from the celestial coordinates.

The operators of the measuring machine carefully note the length of the streaks, as well as the brightness of the meteor along its path. Thus, observation gives three important facts: the path, the velocity, and the brightness (or intensity) at any time. It remains for the physicist and the mathematician to interpret these data.

Two fundamental relations are needed, one relating to drag on a projectile, the other to the correspondence of loss of mass of a meteor with its light intensity. These equations are:

$$\text{(I)} \quad a = -K\rho m^{-1/3}v^2$$

$$\text{(II)} \quad I = \frac{T(v)}{2}\frac{dm}{dt}v^2$$



This approximate sketch shows the outline of the projected f0.67 Schmidt camera to be used in meteor studies.

Shown here are three of the machines in use at the M. I. T. Center of Analysis for determining distances between points on a photographic plate.

where

v = velocity of meteor
a = acceleration of meteor
K = drag coefficient
ρ = density of the air
m = mass of meteor
I = light intensity
$T(v)$ = luminous efficiency coefficient
t = time

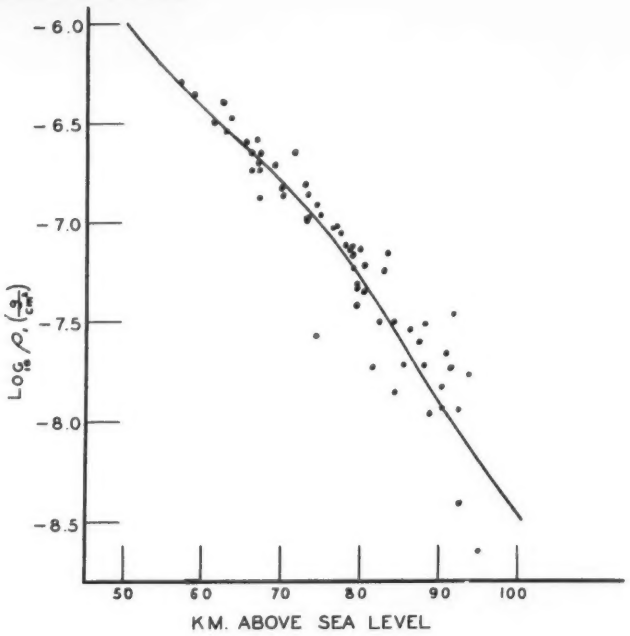
The object of the whole project is to find extensive properties of air at various heights. Certainly, the density in equation (I) is such a property, so if it were possible to find the acceleration, velocity, and the mass of the meteor at height h, then one could find the density at height h also. As a matter of fact, however, the velocity is known along the path; from its variation its acceleration can be verified. How about the mass? One might reasonably expect from conservation of energy that the intensity of light emitted by the meteor should bear some relation to the rate at which the meteor loses kinetic energy $\left(\frac{dm}{dt}v^2\right)$, for the light is due to frictional heating and subsequent oxidation of part of the meteor. Indeed, such a relation has been determined experimentally, and the rate of mass loss has been found proportional to the intensity of the light and inversely to the square of the velocity as in equation (II). The term $T(v)$, known as the luminous efficiency coefficient, is itself a function of the velocity, and experiment shows that for values of the velocity concerned here, a $T(v)$ proportional to the velocity is adequate. Thus the mass at time t can be found by numerical integration of the expression, using as the lower limit the time when the mass equals zero, the meteor being extinguished. Using this value of the mass in equation (I), air density can be found for varying heights, and the problem is solved.

It seems appropriate to remark that there is a theoretical relation between air density and height, given by the well-known barometric equation:

$$\rho = \rho_0 e^{-\frac{Mgh}{Rt}}$$

where

ρ = density of air at height h
ρ_0 = density of air at sea level
e = base of natural logarithms
M = molal weight of air
g = gravitational acceleration



h = height
R = gas constant
T = Kelvin temperature

Thus one would expect air density to fall exponentially with height. It is to be noted, however, that this equation applies only to isothermal systems; indeed, it is just the atmospheric variations in temperature (see above) which render this relation useless for practical application to the study of the upper atmosphere. In fact, temperatures derived from the calculated densities of the atmosphere up to 100 kilometers vary considerably with the height.

Thus we have a picture of the air mass surrounding our earth. By theory, the density should fall off in an orderly manner as we climb, in air just as in liquids, but to an extent greatly exaggerated by the compressibility of the former. But this is not the case; temperature differences in the upper atmosphere give rise to sharp density gradations — alternate layers of dense and rare air. Current theory attributes the temperature differences to varying absorption of solar heat. Whatever may be the cause, there is an unexpected variation in air density which could be verified only by observation. It is often the case with nature, that it is possible to observe secondary effects if not the actual phenomena. By astute application of this principle scientists have bared the mysteries of the upper atmosphere.

the problem of the bad penny

By John G. Stevenson, '49

Is He Right?

A man is given twelve pennies which are identical in size, shape, and appearance. He is told that eleven of them are also identical in weight, but that the remaining one is bad. However, he does not know whether the bad penny is heavier or lighter than the rest. In order to determine which coin is bad, he is supplied with a balance, but no supplementary weights. All he can do is balance pennies against pennies. The problem is that in only three weighings, he must locate the bad penny and be able to say whether it is lighter or heavier than the rest.

In order to solve this problem, we first divide the coins into three groups of four each. Two of these groups are balanced against each other. If they balance then we know the bad penny is in the third group. This first weighing has done something else of value, however. It has established that if the two sets of four balance, any one of them may be used as a coin of standard weight. Having thus found the group to which the bad penny belongs, we proceed to consider the location of the bad penny from a group of four using two weighings. Taking this group of four, we put one aside. Two of the remaining three coins are put in one scale pan, and the third is put in the other scale pan along with a standard penny. If these balance, the penny we left out must be bad. Which way it is bad can be determined on the third weighing by comparing it with a standard penny and noting the position of the scale pans. To consider the case in which the groups of two do not balance, the following schematic diagram may be of aid. Numerals indicate coins about which nothing is yet known, and the 'S' represents a standard coin.

1 2

3 S

If the scale pans take the position shown, then we know that either 1 or 2 is light, or else 3 is heavy. 1 and 2 are then balanced against each other. If they balance, 3 is heavy. If they do not, then inspection of the position of the scale pans will indicate whether 1 or 2 is light. The analysis is exactly similar if the position of the scale pans shown above is reversed.

The more difficult case is when the two groups of four do not balance on the first weighing. Suppose the scale pans take the following position:

1 2 3 4

5 6 7 8

The next step is to put 6, 7 and 8 aside and rearrange the coins as follows:

1 2 S

3 4 5

The scale pans are shown in an unbalanced position. If they balance, then the bad coin must be in the three that were set aside and can be determined by the method shown above. If the scale pans take the position shown, either 1 or 2 is light or else 5 is heavy. The method for determining which it is has been described. If the scale pans take a position opposite to that shown, the only possibility is that either 3 or 4 is light. Again we can find out which by comparison with a standard coin.

This brings us to the general case of determining a bad penny from m pennies in n weighings, as well as the question of determining the maximum number of coins from which a bad one may be selected in a given number of weighings, say, n. It is important to note that the maximum number of coins from which a bad penny may be selected in a given number of weighings is materially increased with the original knowledge that the bad penny is either heavy or light. In the case of two weighings, we can make the selection from nine coins, but without knowledge we can make the selection from only four. In the case of three weighings, the maximum number from which a selection can be made without knowledge is 12, as we have seen. With knowledge, we may select from 27. This suggests the general rule that in the case where we originally have knowledge, the maximum number from which a selection may be made is 3^n. For the case in which we originally have no knowledge of the direction of bias of the bad coin, the relation between the number of weighings, n (n must be greater than one, since one weighing without knowledge is obviously impossible) and the maximum number of coins from which a selection may be made is:

$$m = 3^{n-1} + 3^{n-2} + 3^{n-3} + \ . \ . \ . + 3^{n-n} - (n-2).$$

In cases where m and n satisfy this relation, that is when we have the maximum number of coins for a given number of weighings, the first step is always to set aside the maximum number of coins from which a selection may be made without knowledge in $n-1$ weighings. Thus if we wish to select a bad penny from 38 coins in four weighings, then we must first set aside 12 coins, because if the remaining coins balance we have only three weighings left and still know nothing about this 12. Thus 38 coins in four weighings without knowledge may be reduced to 26 coins in three weighings with the knowledge gained from the first weighing. In case the two sets of 13 do not balance on the first weighing, then nos. 18–26 are set aside from one scale pan (note that this is nine coins — just the maximum number from which a selection can be made in two weighings with knowledge), and the following rearrangement is made:

14 15 16 17 *5 6 7 8 9 10 11 12 13* (left pan)

1 2 3 4 S S S S S S S S S (right pan)

It was assumed that the original balance of the pans was the same as that shown. If this condition prevails after the switch, then the bad coin is in the underscored group. If it reverses, we must investigate 1–4 and 14–17. This may be done by putting 14, 15, and 4 aside and switching 17 and 1, thus:

S 16 1

17 2 3

The bad penny may now be located in the remaining two weighings as before.

Note that before the second weighing, we remove from one scale pan the maximum number of coins from which a bad one may be determined with knowledge in $n-2$ weighings. This number is replaced by standard coins and the remaining coins in this scale pan are switched with an equal number from the other pan.

"....of driving gentle machinists mad"

By Helmut E. Weber, '50

"Your college training qualifies you for the job, but what practical experience do you have? . . . Sorry, we're looking for a man with more experience."

Anyone who has spent most of his time in school studying for his engineering degree may have heard those same words spoken to him by some personnel director. And, as is repeatedly the case, the man with the practical experience gets the nod for the job. Possibly the man who was turned down could, if given the chance, do the job better than the one chosen. But the personnel director represents a company which bases its decisions on past records of men hired with and without practical experience. The evidence is conclusive, and proves that men with some practical experience to supplement their schooling invariably are a greater asset to the company than those with only an engineering degree.

To a potential engineer about to enter industry shop experience is invaluable. It provides a knowledge of three major factors necessary to modern industrial production — machines and equipment, materials, and shop labor.

Each of these factors imposes practical limitations on the job of an engineer. And when the engineer has gained a thorough understanding of these three factors, he has in his grasp knowledge which is at least as valuable as his engineering degree.

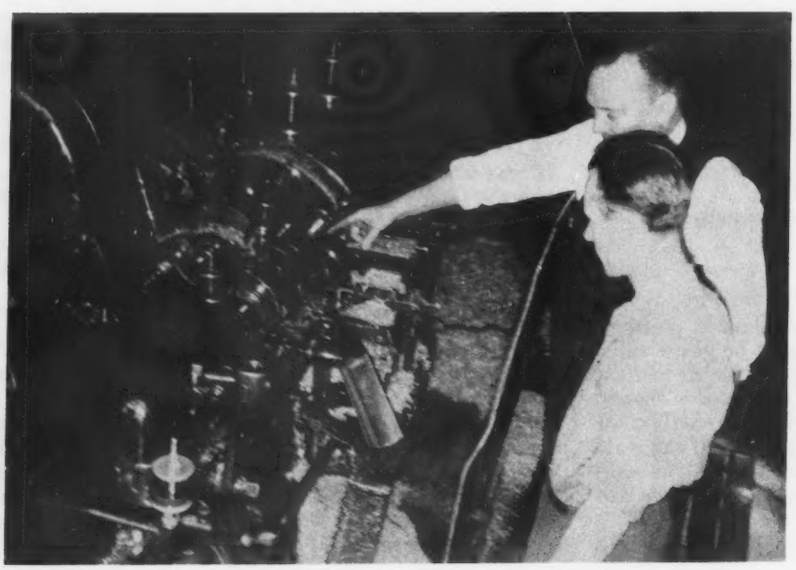
The first of the three factors entails a thorough knowledge of the types and sizes of the machines used in production. An engineer must know how parts are made, which machines can do desired operations, and which machines can do those operations most efficiently. Without this information an engineer may well waste his continued efforts on impractical designs and jobs, as well as making a fool of himself in the eyes of the other employees.

One may laugh at the apparent absurdity of the following case but realize that its basic theme is so often true and sadly so.

"The designer sat at his drafting board
A wealth of knowledge in his head was stored
Like 'What can be done with the radial drill
Or a turret lathe or a vertical mill?'
But above all things a knack he had
Of driving gentle machinists mad.
So he mused as he thoughtfully scratched his bean:
'Just how can I make this hard to machine?
If I make this body perfectly straight
The job had ought to come out first rate,
But it would be so easy to turn and bore
That it never would make a machinist sore.
So I'll put a compound taper there
And a couple of angles to make 'em swear.
And brass would work for this little gear,
But it's too damned easy to work, I fear,
So just to make the machinist squeal
I'll make him mill it from tungsten steel.
And I'll put these holes that hold the cap
Down underneath where they can't be tapped.
Now if they make this, it will just be luck
'Cause it can't be held by dog or chuck
And it can't be planed and it can't be ground
So I feel my design is unusually sound!
And he shouted in glee, 'Success at last!
This damn thing can't even be CAST!' "

The Marquette Engineer

After a man sees and understands the operation of a centerless grinder, a vertical boring-mill, or the ordinary lathe, he will know that a particular part can be more efficiently made on certain machines than on others. As extreme examples consider the machining of a connecting rod from bar stock which could be



The apprentice engineer must know how to handle the tools, such as this turret lathe, which will convert his designs to actuality.

Once they are in use, machinery and processes must be checked and controlled continuously

An engineer must know how to test the performance of his designs when they are in actual practice.

efficiently forged, or the grinding of a clearance hole rather than using only a boring or drilling operation.

The limitations of the production facilities available force the engineer to find some convenient solution to a problem. "Improvise" becomes his by-word. If his perfectly good centrifugal pump refuses to pump water from his eight-foot well, he finds another solution — a solution probably not found in a text on fluid mechanics. After the engineer has become familiar with shop practices he finds that engineering problems are more easily solved. His knowledge of machine operations opens to him new and more efficient methods of production.

In the same connection consider the second factor. The possibility of having a choice of several different materials with which to do a job presents the problem of efficient selection. What function must the part perform — does it require strength — how hard must it be — is finish important? These factors and others must be weighed against the ease and costs of production and the good engineer can select the material best suited to the purpose in mind, because shop practice has given him an insight into the importance of the qualities and properties attributed to different materials. A good engineer knows how to balance material specifications against cost — an ability which again can hardly be developed with only a textbook.

Lastly, working with the shop employees themselves gives a man that valuable insight into their habits, tendencies, and reactions. He finds that there are certain things a man will and will not do and the reasons why. For this insight an engineer requires not a single course in modern psychology. In fact, with an understanding of the first two factors he will invariably gain the confidence of the shop employees. When they know that an engineer's judgment is sound, it is almost surprising how much more quickly and easily his plans are executed.

The value of practical experience should now be an established fact. And much of this valuable experience can easily be acquired by a student working in a shop during his summer vacations. While schooling cannot be replaced by practical experience, neither can any amount of schooling provide the knowledge afforded by experience in the shop. Each has its place in the education of a good engineer, and each is an invaluable asset toward acquiring a better job after the student's graduation.

alice in dimensionland

By Luis H. Bartlett

The author of this weird tirade offers sincere apology to the beloved memory of Lewis Carroll and cites, as a very lame excuse, the chance remark of a certain teacher. In substance, this remark set forth the opinion that entropy is an abstraction, so evanescent that it may not be grasped by students and, consequently, any explanation of this property is wasted in the classroom. The teacher shall remain forever nameless, but he is accurately portrayed by the Walrus in relating the lecture by a "Very Learned Professor." In case the reader should ever meet and recognize the gentleman, please do not bother to explain the concept of Entropy to him.

The sun was gleaming in the sky
To pour out energy,
And doing the very best he could
To increase Entropy.
But Entropy is nothing else
Than dq over T.

The Walrus and the Carpenter
With tears bedewed the street.
For they were very sad to see
Such quantities of heat
Were being wasted every day.
It nearly had them beat.

The time has come, the Walrus said,
To speak of Engineering,
Of Pressure, Volume, Enthalpy,
Of shiny Engine Gearing,
And how to use this energy
By Isentropic steering.

Entropy, said the Carpenter,
Is silly as can be.
It's purely theoretical
As any fool can see.
But this is false, because you know
It's dq over T.

"The verses sound nice," Alice mused, "but what do all those big words mean?"

"Oh, most of those big words are the names of dimensions," the Walrus replied, "and we always use dimensions to describe things accurately. All dimensions are conveniences which were invented to make things easier."

"You and your dimensions!" Alice was losing patience. "What on earth are they?"

"As I was saying," the Walrus paused dramatically, "dimensions are a great convenience. Many things are difficult to handle without dimensions, and, in some respects, they are similar to handles. Suppose you have something which is so clumsy that it is difficult to grasp easily. You merely pick out a convenient handle or dimension and remove that, then, from what is left, you take out another dimension, and so on until it is all component dimensions which are easy to grasp."

Dr. Luis Bartlett, author of *Alice in Dimensionland*, a recognized authority on refrigeration, and consequently well qualified to burlesque entropy, is Director of the Engineering Experiment Station at Louisiana State University.

"How do you take out a dimension?" Alice inquired. "Is it like taking a raisin from a piece of fruit cake?"

"Oh, not at all," explained the Walrus, "you merely have to divide by the dimension. For example, suppose you buy 10 bushels of peaches for $25.00. The financial dimensions of this transaction are twenty-five dollars and 0.40 bushels per dollar. You divide the twenty-five dollars into the 10 bushels, and there are your two financial dimensions."

Alice pondered this difficult mathematical feat and then insisted, "But what became of the peaches? You can't eat financial dimensions, and is money a dimension?"

The Walrus was greatly encouraged. "Well, I'm certainly pleased by your unusual intellectual ability. So many people confuse things with their dimensions. Of course, you can't eat a dimension, financial or otherwise. Money is used as a dimension, but some people measure everything in terms of dollars, and nowadays dollars shrink so badly from the effects of income tax, inflation, and social security. Come, now I'll show you some other kinds of dimensions.

"This little room is our Space Stockroom. When we receive a shipment of Space that is too large to fit in here, we merely divide it into its component dimensions and store each one separately. This bin contains Length, this one is filled with Breadth and the third one is for Depth dimensions."

"But they are all empty," said Alice. "Isn't there any space in stock?"

"Oh, yes," replied the Walrus, "right now there is more than ever. You see length has only one dimension so it does not take up any space at all and the bin will hold any amount we put in. Breadth and depth are quite similar in their properties. This makes it very convenient. When you need more space, you merely take the required amount of each dimension. multiply them all together and there is your space. Simple, isn't it?"

"Well, when you put it that way, it sounds quite simple," Alice had to admit, "but suppose someone comes in here when it is dark and picks up three length dimensions out of one bin. What would he get when these were multiplied together?"

"Oh, that's even simpler. You must remember these dimensions are purely imaginary, thus the first one he picked up is length, the second becomes breadth and the third becomes depth. Multiply them together and at once your space appears."

This abstruse dissertation stunned Alice completely. The Walrus twitched his whiskers in a perplexed manner and murmured to himself, "Perhaps we should look at something that is easier to comprehend." He opened a door that was close at hand, led Alice through and closed it firmly but very quietly.

"Now this is our Energy and Power Department. We store the component dimensions of Mechanical Energy in these bins. When foot-pounds are received, we put the feet in this bin while the pounds are placed in the next one. It is a very compact storage system and when anyone wants some energy, all that is necessary is to take one foot and one pound and multiply them together, then it's all ready to go."

Alice considered this gravely and then brightly asked, "How can the foot-pound go anywhere if it has only one foot?"

The Walrus hastily changed the subject. "Sometimes there is so much Mechanical Energy in storage that it becomes necessary to convert part of it into Thermal Energy. We do this by merely multiplying the Mechanical Energy by the reciprocal of Joules Constant. See, like this." And he wrote on the blackboard

$$Adw = dq$$

"Now this is a special statement of the First Law of Thermodynamics."

"Oh, that terrible word!" Alice reproved. "If you were my little boy, I'd wash your mouth out with soap."

"I'm sorry," the Walrus squirmed uncomfortably. "I'll not say it again. But to continue, A represents the reciprocal of Joule's Constant, dw indicates Mechanical Energy, and dq is Thermal Energy. American engineers commonly use British Thermal Units to measure Thermal Energy."

Alice was very indignant. "They can't be very patriotic, or they would use American Thermal Units."

"Shh," cautioned the Walrus, "you may stir up an International Incident with such loose talk. However, we had better use just *Btu* for the unit and then there can be no hard feelings anywhere, particularly as it has been re-defined by the International Steam Table Conference at London in 1929, in terms of electrical units. Poor thing, it has been almost worn out with re-definitions."

"Now, let's go over and look at the Division for Storage of Thermal Energy in its Component Dimensions. This fenced enclosure is occupied by the D. S. T. E. C. D. and some very peculiar people work here."

"It sounds like a New Deal Agency to me," said Alice. "Do you think they will let us in?"

"Will you hold your tongue?" the Walrus whispered indignantly. "You will get me into trouble with the Administration yet. Here we are inside and do be careful!"

Alice looked in wonder at an enormous number of peculiar entities of all sizes sprawled upon the ground, completely inert and apparently without any rhyme or reason to their arrangement. Some were very large and others were tiny, but all were identical in shape. She rubbed her eyes in amazement, then asked, "What are these poor creatures, shaped exactly like the letters *ds*?"

"Oh," said the Walrus with marked contempt, "we called those Entropies. They have enough energy, but it is all divided by Absolute Temperature and is isothermally unavailable. You see, each one of these is the extensive dimension of an increment of Thermal Energy. When Thermal Energy enters D. S. T. E. C. D., we un-integrate to convert it to the differential, and this can be divided into the intensive dimension T and the extensive dimension ds."

Turning to the blackboard, he rapidly wrote some peculiar symbols and explained, "You see, we first un-integrate the Thermal Energy q, like this

$$d(q) = dq$$

but by definition $dq = Tds$, so we can separate the T and put it in this bin and the ds is put on the pile you just passed. It saves so much bother to do it this way and, besides, think how little Space this requires."

"But," Alice asked, "how do you separate the Absolute Temperature from the Entropy?"

"That's easy," answered the Walrus, "you just divide the differential increment of Thermal Energy by the proper T, thus

$$\frac{dq}{T} = ds$$

and there you have an Entropy all by itself, and then put the T in the proper bin. Notice that we are careful to keep all the different sizes of T's in separate bins. There are two rows of bins, as you can see, one for Rankine T's and one for Kelvin T's. Sometimes a shipment of Thermal Energy arrives in calories and we put the Kelvin T's into the second row of bins. Frequently, they get mixed up and the tangle is very perplexing. I hope no scientist ever invents another Absolute Temperature scale. The worst muddle is caused by inexperienced help, who often divide by Fahrenheit t instead of Rankine T. Then they toss these little t's into a bin of big T's, and I have to go along, pick out each little t and add 459.6°. It's really very discouraging, because our stock of 459.6's is almost exhausted and the little t's are so hard to find. The resulting Entropies are also enormously swollen and distorted, poor things, and there isn't anything we can do to help them."

Alice wept disconsolately over the suffering of the misshapen Entropies, then she smiled brightly at a new idea. "But, can't you just reverse the process and then start over again so the little swollen Entropy will come out the proper size?"

The Walrus stroked his beard reflectively. "No," he mused. "Don't you recall Clausius stated, 'Die Energie der Wely ist konstant, die Entorpie der Welt strebt einem Maximum zu,' and while this is a statistical observation, no one has ever disproved it."

"Speak American and don't use such big words to

(*Continued on page 108*)

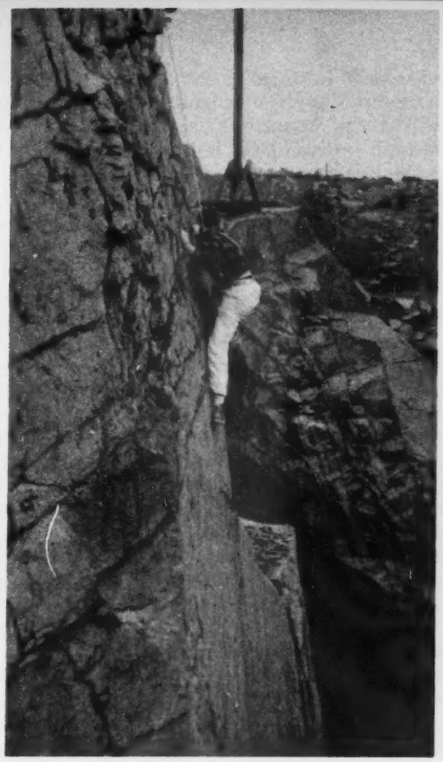
NIGHT AND DAY

Barracks Binge

Last Rubber

The Weekend . . . . .

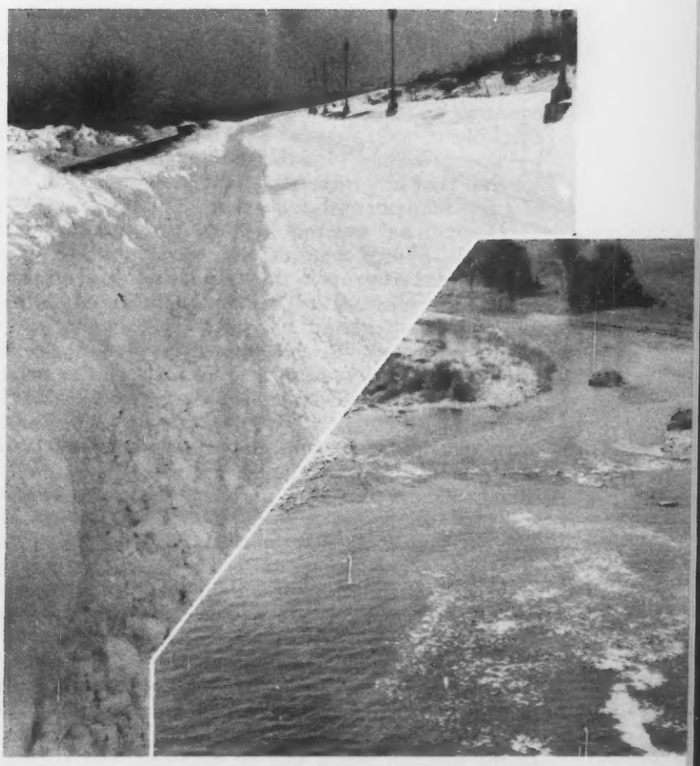
The "Great White Way"



Ever upward

Quick warm-up

Solid and liquid



Thwack!!

no formulas necessary

By Max T. Weiss

Research Associate, Research Laboratory of Electronics

(Condensed for publication from a seminar paper on dimensional analysis)

"What is that formula for the period of a simple pendulum?" A moot question. "Well, the period is in seconds; so the formula must come out to be in seconds, too. I think the period depended only on the length and on 'g'. I'll try:

$$t = C l^x g^y.$$

Expressing this in dimensions only:

$$[T] = [L]^x \frac{[L]^y}{[T]^{2y}}$$

But the L's must cancel out; so $x = -y$, and $2y = -1$.

Now I remember: $t = 2\pi \sqrt{\frac{l}{g}}$."

In a crude but still useful way an imaginary quiz-taker has just used the technique of dimensional analysis. Dimensional analysis has played an integral and significant part in the development of physics and the engineering sciences. Its foundation was laid in 1822 by Fourier, who was the first to realize that physical equations are usually expressed in such a general form as to conserve their validity despite changes in the size of the fundamental units used. This realization led to the formulation of the principle of dimensional homogeneity, which states that all terms in a physical equation must have the same resultant dimension. The checking of any physical equation was made possible by this principle. Furthermore, physicists soon discovered that any quantity could be expressed in terms of a few fundamental dimensions.

Dimensional analysis has had perhaps its greatest utility in hydrodynamics and aerodynamics. Thus, all model experiments in these fields are based on results obtained by dimensional methods. Electrical engineering, on the other hand, has until recently almost completely neglected dimensional analysis. This neglect can probably be attributed to the ease with which electrical phenomena lend themselves to a rigorous analytical approach. Recently, however, electric-motor design and ultra-high-frequency tube design have benefited from a dimensional approach. In theoretical physics, dimensional analysis has long played a significant role and will probably continue to do so in the future, particularly in suggesting new methods of attack on fundamental problems. As an aid in the derivation and comprehension of equations describing physical phenomena, dimensional analysis must be recognized as a useful, almost essential, tool to the scientist of today.

To quote Professor Bridgman, Nobel prize-winning physicist from Harvard, "No investigator should allow himself to proceed to the detailed solution of a problem until he has made a dimensional analysis of the nature of the solution which will be obtained, and convinced himself by appeal to experiment that the points of view embodied in the underlying equations are sound."

Following a brief discussion of the underlying principles and general methods of attack in this field, several interesting problems — including one on the design of high frequency vacuum tubes — will be worked out in some detail.

Dimensional analysis concerns itself with the most fundamental relationships of physical quantities and with the system of dimensions utilized in their description. Since the subject is frequently involved in abstractions regarding the very basic meaning of the mathematical equations used in describing physical phenomena, very careful definition of terminology and rigorous reasoning are essential if confusion is to be avoided. The endless controversies regarding the basis of dimensional analysis are sufficient proof that a study of some of the basic concepts of physical science is necessary for a clear understanding of the subject and its growth.

Physical science is fundamentally concerned with the measurement of quantities and the relationships among these quantities. Clearly, two factors are necessary in order to specify a physical quantity: (1) a numerical value, (2) the unit employed. Thus: Quantity = Numeric × Unit.

The numeric, of course, varies with the size of unit chosen. However, the ratio of two quantities of the same kind is independent of the unit. For instance, one can say that a particular automobile travels twice as fast as another without specifying the unit of velocity. This property of physical quantities is called by Bridgman "the absolute significance of relative magnitudes." It should be noticed that this requirement is not essential to make measurement possible. Thus a quantity may be defined by the equation $Q = \sin t$, where t is the measure of time. Although this may be a perfectly possible defining equation of a quantity, the ratio of two such quantities certainly depends on the unit of time chosen. However, in physical science, quantities which do not obey the principle of the absolute significance of relative magnitudes are excluded from consideration.

Fourier, who may be called the father of dimensional analysis, introduced in 1822 a new concept by stating that every physical quantity has a dimension associated with it as well as a unit. Thus, a rod can be measured in terms of meters, yards, or miles. All of these units have the common quality, however, that they are lengths and not, for example, areas. This fact can be stated as follows:

$$\text{measure of rod} = \text{number} \times \text{unit} \times (L),$$

where (L) represents the dimension of length.

Rather than giving each new quantity its own independent dimension, it is far more convenient to express the dimensions of a quantity in terms of a number of fundamental dimensions. If the dimension

of a quantity is thus stated in terms of other fundamental dimensions, it is termed a "derived" dimension. For instance, the dimensions of velocity are $L/T = LT^{-1}$ rather than V, if the usual fundamental dimensions of L, M, and T are used. The meaning of this dimensional formula $V = LT^{-1}$ is that the number giving the measure of the velocity of an object is obtained by dividing a number which measures a length associated with the object (in this case the distance traveled) by another number which measures a time associated with the object (the time taken to travel this distance).

The choice of the fundamental dimension is, in general, arbitrary, although as a matter of economy in symbols as few as possible should be used. The minimum number "which will form a consistent and complete set for a field of science" is called a dimension system. The various dimension systems of the different fields of physics are described later.

It may be of interest to note that since the fundamental dimensions can generally be chosen arbitrarily as long as they are independent of each other, it is meaningless to state "the" dimensions of a physical quantity until the dimension system used is specified. Accordingly, it cannot be considered that we are in some way getting at the ultimate nature of things by writing their dimensional formulas. This viewpoint is far from attaining universal acceptance as yet. Although Bridgman, Planck, and many of the more recent writers in the field attach no significance to the "true" dimensions of a quantity, most of the earlier and many of the present-day physicists such as Maxwell, Rayleigh, Rucker, and Tolman see something absolute in a dimensional formula.

In mechanics it has long been recognized that the minimum number of fundamental or primary dimensions in terms of which all mechanical quantities can be expressed is three. In physics and in much of engineering these three fundamental dimensions are usually chosen to be length (L), mass (M), and time (T), which comprise the dynamical or physical dimension system. All mechanical quantities can, of course, be stated in terms of (L), (M), and (T).

Another dimension system which is widely used in the engineering literature is the gravitational or technical system. The fundamental dimensions in this system are force (F), length (L), and time (T). This technical dimension system has some advantages in the engineering field because of the prevalence of force and related quantities, such as stress and pressure, in engineering calculations. William Ostwald proposed in 1891 the use of an energetical dimension system in which length (L), time (T), and energy (E) are taken as fundamental. This system also simplifies the dimensional forms of many of the important mechanical quantities and is of special appeal to many scientists because of the universally fundamental nature of energy.

The astrophysical dimension system has as its fundamental dimensions, length (L), mass (M), and the gravitational constant (k). One objection to this system is that it advances a proportionality constant to the role of a fundamental dimension. This is, in general, inadvisable because of the usual temptation to drop the dimensions of the proportionality constant entirely with resulting confusion.

In the early history of electromagnetism, electrical phenomena were considered to be entirely mechanical in nature. The consequent suppression of the dimensions of the proportionality constants ϵ and μ has caused endless confusion and contradictions in the study of electromagnetism and has made the checking of the dimensional homogeneity of equations almost impossible. At present, the necessity of choosing a fourth fundamental dimension, such as charge or resistance, is being recognized by most physicists.

The minimum number of fundamental dimensions required to express thermodynamic quantities is four as was stated first by Fourier in 1822. Nevertheless, numerous papers on thermodynamics appeared much later in which only three fundamental dimensions were utilized. The following quotation from a paper written in 1915 by E. Buckingham will serve to illustrate both the general and the specific thermodynamical criteria used in determining fundamental dimensions:

"What do we mean when we say that a given kind of physical magnitude can be derived from certain other kinds which we call fundamental? We mean simply that experience has shown that if we use, or combine, certain particular magnitudes of the fundamental kinds in a prescribed way, we thereby determine a magnitude of the derived kind, the size of this resulting derived magnitude being dependent only on the sizes of the particular fundamental magnitudes with which we started, when once the method of using them has been specified . . . Now there is no known (theoretical) process by which, having available only standards of mass, length, and time, we can fix and reproduce any temperature." Thus the mechanical system is extended to thermodynamics by adding a thermal dimension, which has universally been chosen as temperature.

Although dimensional analysis has its greatest utility in deriving relations between measurable physical quantities, it also finds application in changing units. There are two types of unit changes possible. In the first type, merely the magnitude of the fundamental unit is changed. Lodge, in 1888, showed how the theory of dimensions could be of aid in this unit change. His idea can be summarized in the following rule:

The dimensional formula for the physical quantity being considered is written down, with the dimensional symbols treated as the name of concrete things. Each symbol is then replaced by its equivalent in terms of the new unit of measure which is to replace it.

This rule can be clarified by means of a concrete example. Suppose a velocity of 100 feet per second is to be expressed in miles per hour. This can be done as follows:

$$100\frac{L}{T} = 100\,\frac{1\text{ ft.}}{1\text{ sec.}} = 100 \times \frac{1/5280\text{ miles}}{1/3600\text{ hours}}$$

$$= 100 \times \frac{3600\text{ mile}}{5280\text{ hour}} = 68.163\text{ mile/hour.}$$

Although this example may appear trivial, this method is nevertheless very useful in more complicated problems.

The second type of unit change involves a change in the type of fundamental unit used and not merely a change in the magnitude of the unit. This type of change is not always possible and in any case is considerably more complicated.

It has been shown that all terms in a physical equation must have the same resultant dimensions if dimensional analysis is to be applicable. It can also be shown that every secondary quantity which satisfies the requirement of absolute significance of relative magnitudes must be expressible as some constant

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the tech engineering news

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from the editor's notebook

Multiperception, Format, and Surplus Engineers

"The present generation now, not even in their teens, will act differently. They will find it easy to study, read books, listen, and look at the television set simultaneously." We might think this is a difficult order, but it really is not. We found this quaint little item in the December issue of *Radio-Electronics* under the heading "Multiperception." Perhaps we can get some of this miraculous coming generation to do the studying for all of the finals simultaneously — a feat regrettably rare at present.

Now that the above gem of knowledge is off the editorial chest we will explain our new format. To allow more room for articles, and incidentally improve the "punch" of the start of the magazine, the biographies of authors — in a more informal and concise form — are now included together with the editorial on this page. The hope is, as is normal, to make the editorial and biographies more informal and interesting. Amen.

"To everyone, the coming surplus of engineers means that steps must be taken to limit annual engineering graduates to a number that can be absorbed by industry without lowering the already low standards of pay for engineers." This intriguing quotation from the *Cooperative Engineer* editorial would seem to be evidence of a dangerous and unwarranted tendency toward a narrow trade-unionism in engineering. The editor then continues that curricula must be extended, academic standards raised, and professional status for engineers made mandatory in order to achieve his goal.

Hasn't experience shown that academic rating often is but a poor measure of a man's actual future value? Originality is an essential asset often given too little weight on a grading scale. By all means let every possible man get his engineering degree; let time sift out the incompetent ones. By the same token a man should be eligible for any position on his merits alone, without regard to possession of a degree.

After all, the engineering degree would do no harm to its holder even if not put to actual use. Or would it? It is at this point that the counter-argument hits a snag. In the first place, just that much time of both student and instructor has been wasted. Perhaps more important are possible social consequences: One of the factors most widely accepted as a cause of the rise of Fascism was the presence of a surplus of men with "higher" learning in Europe.

Perhaps, therefore, a weeding-out process might be desirable; but what kind of process?

Who's Who

Having tried to solve the bad penny problem before, the editorial staff was able to appreciate to the hilt **John Stevenson's** contribution; he even stuck his neck out and gave a general solution. John won some math awards at St. Paul's school and then had ample opportunity to practice his gifts while an infantryman, waiting to resume his career at Tech. **George Field,** as one might expect, is a charter member of the new M. I. T. Astronomical Society, and a physics major in preparation for graduate work in astronomy. **Max Weiss** is a Research Associate at the Research Laboratory of Electronics over in Building 20. He graduated from C. C. N. Y. as an electrical engineer, but is now working for his doctoral degree in physics after years of doing research for the Navy on automatic mines. **Hal Weber,** our business manager, is well qualified for his subject by virtue of the three years he spent in various Milwaukee shops inspecting everything from automatic oil controls and aircraft controls to electric motors and industrial diesels.

alice in dimensionland

(*Continued from page 101*)

show how smart you are," snapped Alice, "and tell me what on Earth you are talking about."

"Well," the Walrus answered, "I am not certain about the first part of the quotation. It is vaguely connected with the Conservation of Energy Principle, but the second part stated flatly that Entropy must increase and this means that swollen Entropies just have to stay that way."

Alice showed signs of distress again, so the Walrus hastily reassured her. "You don't have to feel sorry for those Entropies, they are merely coordinates and they have no feelings at all."

"That's much better," Alice said in a brighter vein, "but just what are coordinates and why don't they have feelings?"

The Walrus was very evidently caught off guard and confessed in a low voice, "I am not at all certain, but it seems I faintly remember that a coordinate is used to measure something. Why to be sure! Of course! A coordinate is a dimension. Entropy is a dimension of Thermal Energy and dimensions can't have any feelings, they just can't."

Speaking with great assurance the Walrus continued, "I once heard a Very Learned Professor lecture. He had so many degrees that several ponderous volumes were necessary to list them. In addition he was included in the membership list of every learned society ever known and several were created for his especial benefit. His ideas about Thermal Energy were surprising. He said Entropy is purely a mathematical concept and cannot be directly measured or appreciated. However, this is not at all surprising, since very few dimensions can be measured directly. No one except we two ever saw any Entropy, but so far as that goes no one ever saw an Ampere or a pound of mass. These things won't hold still long enough to see and measure."

A bright thought struck the Walrus. "Who wants to measure things directly, anyway? I'll let you in on a secret if you'll cross your heart. I'm going to invent a method of telling what size shoes a man wears by multiplying the length of his nose by the color of his hair."

"I won't mention it to a soul," Alice agreed. "But suppose the man is bald."

"I never thought of that," the Walrus had to admit. "It probably isn't practical. But to get back to the learned lecturer."

"Oh, fiddlesticks, what do you think I care about your Professor?" Alice emphasized with a stamp of her foot. "What do you do with all the Entropies lying on the ground when it rains? I should think they'd catch their death of cold."

"No, no," the Walrus reassured her. "As a matter of fact, we have to put them in a working fluid before we can use them and water is as good as any, so a little rain won't hurt. There is the Carpenter right now, putting Entropies into some working fluid. See, he puts in an Entropy and then an Absolute Temperature, and at once an increment of Thermal Energy is formed in accordance with the equation

$$Tds = dq.$$"

"You see," the Walrus explained, "it is very difficult to carry Entropy and Absolute Temperature. Unless you can put them in a working fluid, they slip right through your fingers and get lost. In some respects, they are like ideas. If you pick up an idea and don't have an intellect handy, it will surely get lost. Some people try to keep ideas on paper, but it is a very poor substitute for the brain."

Alice digested this statement for some time before asking, "But does this new Nuclear Energy have Entropies also?"

"Oh, yes, indeed," the Walrus stated firmly, "that is, it has Entropy if it is in the form of Heat. In no wise does Nuclear Energy contravene the Second Law."

"What is that queer machine standing on the huge pile of paper?" Alice was very curious. "It has so many big shiny wheels, and the Carpenter is pouring in the working fluid with all the poor little Entropies and the big Absolute Temperatures."

The Walrus cleared his throat and spoke very impressively. "This is the only Carnot Engine in existence that actually works. Originally we put in a concrete foundation, but it was quite unsatisfactory. We then heard that the Carnot Cycle works only on paper. Since the paper foundation was installed, it has worked perfectly, and we are very proud of it. Notice how the Carpenter feeds T and ds into the source of the Engine while T_0 and the same Entropy passes smoothly to the Refrigerator. The available Energy or work done by the Engine, expressed in thermal units, is the Entropy multiplied by the Temperature Drop, thus

$$Adw = ds\,(T - T_0)$$

or if you prefer the more familiar form, just substitute value $\frac{dq}{T} = ds$ in the above equation, and you get

$$Adw = dq\,\frac{T - T_0}{T}$$

Now, since the Carpenter supplied the engine with the Thermal Energy Tds, the Unavailable Energy passing to the Refrigerator is, according to the First Law, T_0ds. You can see for yourself, in accordance with the Second Law, the Entropy is not changed at all by passing through the Carnot Engine."

"I hope no one ever breaks the Second Law and hurts the little Entropies," murmured Alice. "But why do you put Unavailable Energy in the Refrigerator? Is it likely to spoil?"

"Oh, no! It won't spoil," the Walrus reassured her. "We put it there because the Refrigerator is convenient, and besides, it is a good source of the T_0 we need. When we get our postwar low temperature model with a much smaller T_0, we will be able to get more work from one Entropy."

"It isn't fair to make one Entropy do all that extra work." Alice was very indignant. "Why don't you give it some help?"

The Walrus smiled indulgently. "The smaller T_0 helps the Entropy do more work, and it never gets tired anyway. Don't you recall, dimensions don't have feelings, and Entropy is a dimension of Heat or Thermal Energy?"

"Oh, yes! I remember," Alice yawned. "Ho, Hum! I don't mean to be rude, but I am so tired I could just curl right up and go to sleep." And she did just that.

"Humm!" the Walrus murmured perplexedly. "It's funny how a little Thermo puts people to sleep, but, come to think of it, I'm a bit drowsy myself. I'll just curl up here with the Entropies and take a nap."

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BELL TELEPHONE SYSTEM

no formulas necessary

(*Continued from page 105*)

multiplied by powers of the primary quantities. The dimensions of any secondary mechanical quantity can therefore be written as: $Q = L^a M^b T^c$. With these statements as a basis, it is possible to formulate a general theory with regard to the forms of the relations which must hold between physical quantities.

The formulation of the general theory would be considerably clarified and illuminated by first considering the solution of a simple problem using dimensional methods. Let it be required to find the period of revolution of a planet of mass m about a sun of mass S. It is supposed that the period depends on the following quantities:

Name of Quantity	*Symbol*	*Dimensional Formula*
Mass of planet	m	M
Mass of sun	S	M
Distance of separation	r	L
Gravitational constant	k	$M^{-1} L^3 T^{-2}$
Time of revolution	t	T

It is now required to find the form of the functional relation:

$$t = f(m, S, r, k).$$

As has been previously shown, the function is expressible in the form of products of powers of the variables. That is (where the symbol $\sum_{i=1}^{N} Q_i$ merely means $Q_1 + Q_2 + Q_3 + Q_4 + \ldots + Q_N$),

$$t = \sum_{i=1}^{N} A_i\, m^u\, S^x\, r^y\, k^z\,.$$

By the principle of dimensional homogeneity it is also known that the dimensions of every one of the product terms of the right-hand side must be the same as the dimensions of t. Therefore, the dimensions of a typical product term, $m^u\, S^x\, r^y\, k^z$, which has the dimensions $M^u\, M^x\, L^y\, (M^{-1} L^3 T^{-2})^z$, must equal (T). Writing down the conditions on the exponents of (M), the following equation is obtained:

$$u + x - z = 0.$$

Similarly for (L), $\quad y + 3z = 0,$

and for (T), $\quad -2z = 1.$

Therefore, $z = -1/2, y = 3/2, u = -1/2 - x.$

Since there are only three equations with four unknowns it is evident that two of the unknowns, u and x, cannot be uniquely determined. From the relation between u and x, however, m and S must enter in the equation for the period in the following form: $\frac{1}{S^{\frac{1}{2}}} \left(\frac{m}{S}\right)^{\alpha}$.

Hence, the period of revolution can be written as

$$t = \sum_{i=1}^{N} A_i \frac{r^{3/2}}{k^{\frac{1}{2}}\, S^{\frac{1}{2}}} \left(\frac{m}{S}\right)^{\alpha} = \frac{r^{3/2}}{k^{\frac{1}{2}}\, S^{\frac{1}{2}}} \sum_{i=1}^{N} A_i \left(\frac{m}{S}\right)^{\alpha}$$

$$\text{or } t = \frac{r^{3/2}}{k^{\frac{1}{2}}\, S^{\frac{1}{2}}}\, \varphi\left(\frac{m}{S}\right),$$

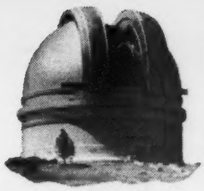
since the $\sum_{i=1}^{N} A_i \left(\frac{m}{S}\right)^{\alpha}$ is merely an arbitrary function of $\left(\frac{m}{S}\right)$.

Thus with the aid of dimensional analysis, it has been possible to obtain a good deal of information regarding the relationship between the period of revolution of a planet and various other parameters.

However, before this dimensional method can be applied generally for the derivation of other physical equations, it is necessary to answer certain questions which may naturally arise in the reader's mind. For instance, one may ask whether it is always possible to predict the applicability of this method in a particular problem. Furthermore, the optimum number and type of fundamental dimensions to be used in any problem must be discussed, and the question of dimensional constants must be dealt with. Finally, in beginning a dimensional analysis of a problem it is necessary to determine the parameters upon which the desired quantity depends. Is there any criterion for choosing these parameters? For example, why were the chemical compositions of the sun and the planet neglected in the previous problem?

First we must state the π theorem, which is fundamental to the whole of dimensional analysis: Any complete physical function, $F(Q_1, Q_2, \ldots, Q_N) = 0$, involving n quantities $(Q_1, Q_2, \ldots, Q_N)$, all of which can be expressed in terms of k primary dimensions, can be written in the form $\psi\ (\pi_1, \pi_2, \ldots, \pi_{N-k}) = 0$, where the π's are the dimensionless products of the variables $Q_1, Q_2, \ldots, Q_N$. Since $\psi(\pi_1, \pi_2, \ldots, \pi_{N-k}) = 0$, then any particular π, when multiplied by a certain function of the other π must be a constant.

(*Continued on page 114*)



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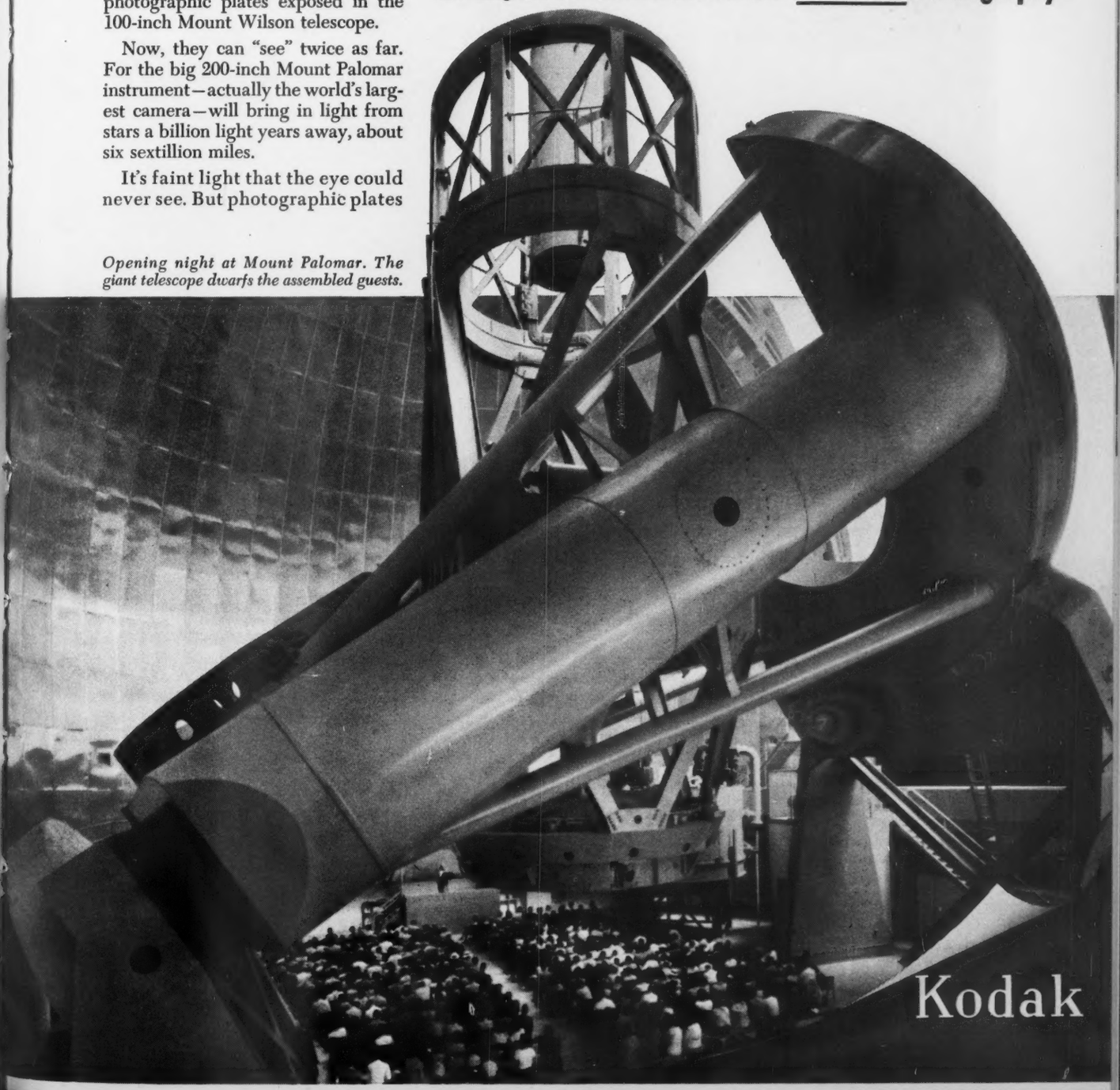

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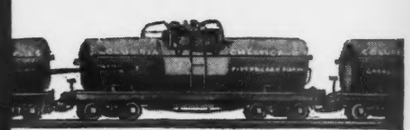

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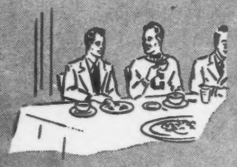

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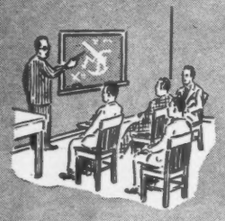

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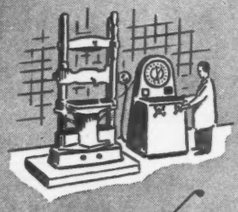

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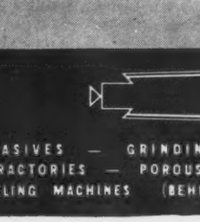

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(*Continued from page 110*)

The meaning of the π theorem and its usefulness will be made clearer by considering some examples rather than by making a detailed abstract development of the theorem. As an example, in the introductory problem on planetary motion the Q's were: $Q_1 = t$; $Q_2 = m$; $Q_3 = S$; $Q_4 = r$; $Q_5 = k$. Since this is a mechanical problem, the number of fundamental dimensions required is three. The number of dimensionless π's (that is, dimensionless products of the variables) is equal to five minus three, or two. One of these is evident upon inspection and is $\left(\frac{m}{S}\right)$. Now, of the remaining quantities, t is of especial interest in this problem. This t must be combined with three other quantities to obtain a dimensionless product. Let r, k, and S be chosen for these three quantities. The second dimensionless product will therefore be of the form $t\ S^a\ r^b\ k^c$. Dimensionally this is $T\ M^a\ L^b\ (M^{-1}\ L^3\ T^{-2})^c$.

Therefore,
$$b + 3c = 0;$$
$$-2c + 1 = 0;$$
$$a - c = 0.$$

Thus $\pi_2 = t\ \frac{S^{\frac{1}{2}}\ k^{\frac{1}{2}}}{r^{3/2}}$, and

$$\psi\ (\pi_1, \pi_2) = \psi\left[\frac{t\,S^{\frac{1}{2}}\,k^{\frac{1}{2}}}{r^{3/2}},\ \left(\frac{m}{S}\right)\right] = 0;$$

or $$\vartheta\left(\frac{m}{S}\right)\frac{t\,S^{\frac{1}{2}}\,k^{\frac{1}{2}}}{r^{3/2}} = 1.$$

Therefore, the equation for t can be written as

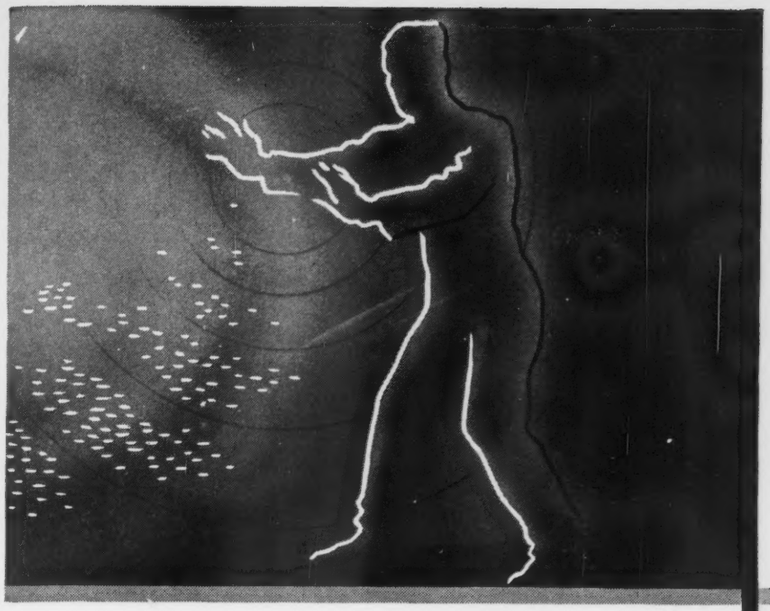
$$t = \frac{r^{3/2}}{S^{\frac{1}{2}}\,k^{\frac{1}{2}}}\ \vartheta_1\left(\frac{m}{S}\right).$$

This agrees with the answer obtained in the introductory problem.

Some of the advantages of the use of the π theorem are evident even from this simple example. It is seen that the theorem systematizes the use of dimensional analysis so that it can be used with little effort. Furthermore, the theorem shows that the result of the analysis may be exhibited in a variety of forms, since the parameters which enter into the dimensionless products frequently may be chosen with a great deal of flexibility.

Now that the π theorem and its method of application have been clarified, some of the questions raised in the introductory problem

(*Continued on page 116*)



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(*Continued from page 114*)

can be answered. Thus, by analyzing a problem by means of the π theorem, the amount of information which dimensional analysis will supply regarding the relationship of the parameters entering into the problem becomes immediately apparent. For instance, if the problem is such that there are four variables and three primary dimensions the theorem shows that there is only one dimensionless product which must equal some constant. Therefore, the problem is entirely solved except for the value of this numerical constant. If, however, there are five variables and three primary dimensions, two dimensionless products will result. The problem will therefore be solved only to within an arbitrary function of one of these dimensionless products, as in the case of the last example. On the other hand, if there are an equal number of variables and fundamental dimensions, a mistake has been made, and at least one more variable must enter the result.

Another important question which must now be answered is how one is to choose the list of physical quantities and dimensional constants among which a relation is to be obtained. In order to answer this question one must realize that dimensional analysis is not a magic formula with which an Australian bushman can solve difficult problems. Dimensional analysis and the usual differential equation method can be considered as merely alternate methods of solving a problem. The background required for both methods is not too different. The former merely requires less mathematical ability and is simpler.

In electrodynamic problems involving the Maxwell field equations, the dimensional constant, c, which is the velocity of light, enters. Therefore c must be included as one of the parameters, as should k in gravitational problems.

Dimensional analysis has had very extensive application in the engineering sciences, particularly in fluid mechanics and aerodynamics. It is especially useful in reducing the number of variables to be considered by showing that several variables can be considered as one dimensionless product. In addition it furnishes a method for determining the conditions under which small scale experiments with models give valid representations of the full scale phenomena, as is explained in most fluid mechanics texts. As Professor Hunsaker has said, "It is no longer necessary to wait fifty years for the analytic solution of a problem if a controlled experiment can be arranged to satisfy the conditions of similitude."

Except for its obvious use in checking equations, dimensional analysis has, in the past, been comparatively neglected by electrical engineers. Its great utility in providing design criteria, especially for electric motors, has begun to be exploited only in recent years.

In the field of electronics, dimensional analysis has also only recently been utilized for design purposes. With the advent of ultra-high-frequencies, it was found that the theoretical study of vacuum tube operation at these frequencies is extremely difficult. G. J. Lehmann and A. R. Vallarino of the Federal Telephone and Radio Laboratories showed that dimensional analysis coupled with experimental work is a powerful tool in this field.

Let a relationship be obtained between oscillator efficiency and the various tube parameters. The variables are outlined below:

Parameter	*Symbol*	*Dimensional Formula*
Efficiency	η	none
Voltage	V	$M\,Q^{-1}L^{2}T^{-2}$
Ratio of electronic charge to mass	e/m	$Q\,M^{-1}$
Current density/dielectric constant	A	$M\,Q^{-1}\,L\,T^{-3}$
Frequency	f	T^{-1}
Cathode-to-plate distance	d	L

In this problem e/m is chosen as a parameter, rather than e and m individually, merely as a simplification, since it is known from experience that e/m always appears as a unit in vacuum-tube space charge problems. Similar reasoning led to the choice of A as a parameter. It may be noted that, in the most general case, this problem involves many more variables than those listed in the above table. However, experience has shown that the parameters listed will give considerable information of engineering importance up to the microwave frequency range.

The six parameters in this problem involve three primary dimensions, $M\,Q^{-1}$, L, and T (since M and Q always appear as MQ^{-1} in

(*Continued on page 118*)

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(*Continued from page 116*)

this problem); according to the π theorem there must therefore be three dimensionless π's. One of these is evidently $\pi_1 = \eta$.

Let $\pi_2 = e/m\ V^x\ d^y\ f^z = (QM^{-1})\ (MQ^{-1}L^2T^{-2})^x \times (L)^y\ (T^{-1})^z$

Therefore, $1 - x = 0$, or $x = 1$

$2x + y = 0, \quad y = -2$

$-2x - z = 0, \quad z = -2$

and $$\pi_2 = e/m \frac{V}{d^2 f^2}.$$

Similarly, let $\pi_3 = A(e/m)^x\ V^y\ d^z = (MQ^{-1}L\,T^{-3}) \times (M^{-1}Q)^x\ (MQ^{-1}L^2T^{-2})^y\ (L)^z$.

Therefore: $1 - x + y = 0$

$1 + 2y + z = 0$

$-3 - 2y = 0$

and $y = -3/2,\ x = -1/2,\ z = +2,$

and $$\pi_3 = \frac{A\sqrt{m/e}\ d^2}{V^{3/2}}.$$

Therefore: $$\eta = f\left(e/m\ \frac{V}{d^2f^2}, \frac{A\sqrt{m/e}\ d^2}{V^{3/2}}\right).$$

It is now proposed to compare tubes of the same type, all operating at the same efficiency. In order for the efficiency to remain constant, the dimensionless parameters inside the functional sign must also remain constant. Noting that e/m is always constant, the following equations must hold:

$$\frac{V}{d^2f^2} = k_1 \quad \text{and} \quad \frac{Ad^2}{V^{3/2}} = k_2.$$

Solving for V from the first of these equations and substituting this value into the second, we obtain

$$V = k_1\, d^2f^2 \quad \text{and} \quad \frac{A}{df^3} = k_3.$$

Therefore, $$d = \frac{k_4 A}{f^3}.$$

It has thus been established that, for a given type of cathode, the distance between electrodes is governed by the $1/f^3$ law. This relation leads rapidly to impractically small dimensions for the tube, and shows why a given type of electronic structure can only be used within narrow frequency limits. From this relation it is also evident that much can be gained by increasing A, the space charge density.

A similar analysis gives the following relation between useful power and frequency: $W = k_5A^5/f^{10}$.

This equation gives the reason for the sharp drop in powers obtainable with increase of frequency. Again, the great advantage in increasing A is evident. It may be noted that all of the above relations were obtained assuming that if d is reduced by a given ratio, all other tube dimensions are reduced by the same ratio. In actual practice, of course, it is not necessary to reduce all dimensions in the same ratio, and the power will not decrease as fast as indicated by the above equations.

Dimensional analysis has played a significant part in theoretical physics in the past and will probably play an even more important role in the future. One of the first to utilize dimensional reasoning in theoretical investigations was Lord Rayleigh. In a paper published in 1871, he showed that the amount of light scattered from small suspended particles will vary inversely as the fourth power of its wavelength — which relation explains the blue color of the sky. In 1911 Einstein developed by dimensional considerations a relation between elastic behavior and infra-red characteristic frequencies later used by Debye in his analysis of specific heat phenomena in a solid.

Another very interesting illustration of this type of method is given by Bridgman in his classic work on dimensional analysis. He examines the possibility of explaining the mechanical behavior of substances on the basis of a particular form of the law of force between atoms; he assumes that this law of force can be written in the form

$$f = Ar^{-2} + Br^{-n}.$$

A is to be intrinsically negative and represents an attractive force, and B is positive and represents a force of repulsion which becomes very intense on close approach of atoms. The coefficients A and B vary for different substances, and the exponent n is to be dimensionless. With these basic assumptions, which are merely intelligent guesses, dimensional analysis enables Bridgman to obtain a general form of Van der Waal's equation as well as several other interesting relations between certain physical properties of a substance and the pressure, temperature, gas constant, A, B, and n. None of these would be accepted by physicists without further analytic and experimental confirmation. The results are sufficiently suggestive, however, to encourage a search for further proof by the orthodox methods. It is in this suggestive role that dimensional analysis will probably prove of great value to the theoretical physicist. This is the crux of the matter: that dimensional analysis can be of considerable assistance in all branches of physical science; but that the utilization of this valuable tool to the best advantage can be effected only by the man who is well grounded in its fundamentals.

DU PONT Digest
For Students of Science and Engineering

a giant on the farm

Products of the laboratory are saving time, toil, money for the American farmer

Through chemistry, farmers are gaining control over many of nature's uncertainties. Costly losses of crops and livestock are being curtailed or prevented. Efficiency is increasing. New applications of chemistry to agriculture are becoming more important than ever as demands for more production increase.

Today, new organic insecticides and fungicides help control insects, plant diseases and blights that threaten crops. Seed disinfectants and protectants help guarantee bountiful harvests by protecting crops in the critical period after planting. Plant hormones hold fruit on trees until fully ready for picking.

Days of labor saved

Du Pont weed killers and explosives accomplish in minutes tasks that used to take hours or days of back-breaking labor. With 2,4-D farmers can kill weeds without harming certain crops. Dynamite removes stumps, digs ditches for draining and irrigation, and loosens the soil to forestall erosion.

New fertilizer formulations meet the changing nutritional requirements of plants during the growing season. Thus the farmer has better control over crop development, and he can utilize his materials, labor and equipment more efficiently.

Feed compounds, developed by industry, are making poultry flocks and livestock herds vastly more productive. Research on chemicals to control animal diseases and internal parasites is making great progress. Control of insect pests is already changing livestock management practices.

Du Pont *agricultural specialist Dr. Arne Carlson, M.S., '40, Ph.D., U. of Minnesota, '48, helps develop sprays and dusts to control fungous diseases.*

Phenothiazine *kills more kinds of livestock worms in more kinds of animals than any other drug . . . promotes normal growth.*

For growth insurance, *farmers treat seeds with disinfectants. "Ceresan" treated wheat gives up to 20% better yields.*

Spraying orchards *controls infestations of insects or plant diseases . . . or holds fruit on the trees until it is fully ready for picking!*

Turning ideas into products

Achievements such as these are the result of Du Pont's team research. An idea may start with one or two individuals. But many specialists—chemists, physicists, biologists, plant pathologists, and entomologists—must contribute their skills before a new product is ready for market. Normally, engineers—chemical, mechanical, civil, and electrical—develop the commercial processes and plants for making the finished products.

The new Du Pont employee, whether he holds a bachelor's, master's, or doctor's degree, enters into this cooperative effort. Yet the immediate group with which he is associated is small and congenial, offering him every opportunity to display individual talent and capabilities.

Find out more about Du Pont and the College Graduate

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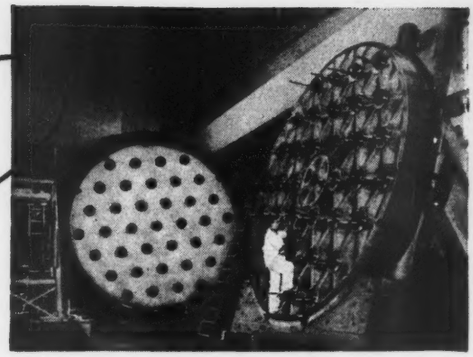
backstage scene from a new celestial drama



Playing a prominent supporting role in a new, exciting drama of the skies is the 21½-ton welded steel structure illustrated at the left. On it was mounted the 200-inch mirror for the giant Mt. Palomar telescope during the delicate grinding and polishing operations. Now it is the mirror's permanent base in the world's greatest eye. Association with this pioneer scientific project is a typical example of B&W's versatility and resourcefulness for serving industry's unusual as well as ordinary needs. Through its great diversity of activity, B&W offers excellent career opportunities in research, engineering, production, sales and other vocations to technical graduates.

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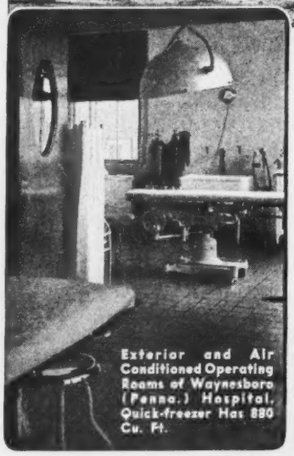
can you do it?

Racking Balls

A mathematician is playing a special game of rotation pool. The balls are numbered from one to fifteen, and after each ball is pocketed it is placed in a correspondingly numbered cubicle in a rack hanging on the wall. The rules of the game stipulate that the row of balls in the rack must never have an interior gap. (Thus, if the eight ball is pocketed the next one must be either the seven or the nine, etc.) The first ball to be pocketed may be any of the fifteen.

Being a mathematician, the player is anxious to learn the number of different orders in which he can clean the table of all fifteen balls, subject to the restrictions given. Can you help him out?

(*Solution on page 124*)



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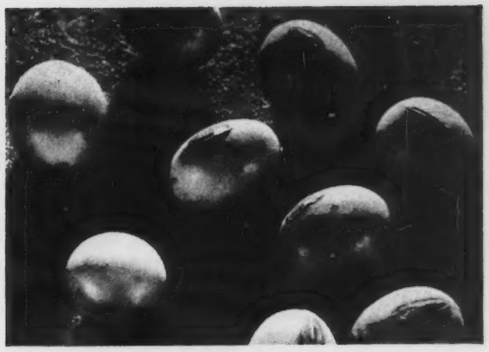
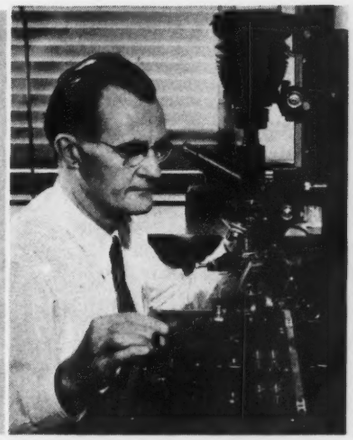
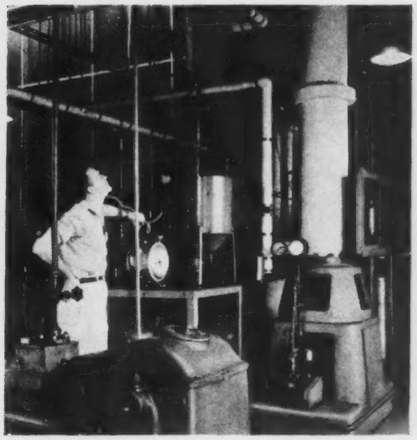


The Versatile Soybean—raw material for many chemical industries — one of many subjects under continuous study at P & G.

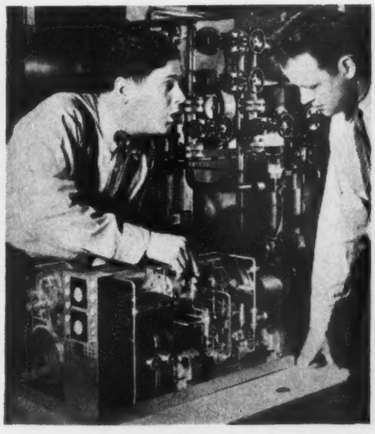
How chemists develop new edible oils . . . and engineers follow through to produce them



1. Chemists conduct microscopic studies on glycerides . . . to develop new edible oils.



2. Chemical Engineers carry on hydrogenation experiments to improve processing procedures.



3. Mechanical Engineers design full-scale factory equipment, using scale models like this edible oil freezer.

4. Other Engineers plan and supervise production operations.

This is just one example of P & G Technical Teamwork in action; similar developments in other fields call for additional men with technical training. That's why P & G representatives periodically visit the country's top technical schools to interview students. If you would like to talk to a Procter & Gamble representative, ask your faculty adviser or placement bureau to arrange a meeting.

PROCTER & GAMBLE

CINCINNATI 1, OHIO

briefing the news

New Forces? . . .

Recently a controversy has been raging among physical chemists over the validity of a research development which tends to demonstrate action-at-a-distance forces between large protein molecules.

Injection of a foreign protein, known as an antigen, into an organism gives rise to substances, known as antibodies, which react specifically with the foreign substance. Using monomolecular films of prepared antigens, Dr. Alexandre Rothen, of the Rockefeller Institute for Medical Research, has measured the degree of inter-action between antigens and antibodies by the depth of a deposit on the screen when treated with a solution containing the antibody.

The surprising part of his research, however, was demonstration of the fact that inert "screens" of substances such as barium stearate, octadecylamine, or a polyvinyl chloride plastic, commensurate in depth with the antigen film, placed over the film did not prevent the deposit of the antibody, although its depth decreased regularly with increased depth of the screen.

Since such action cannot easily be accounted for by forces now understood by physical chemists, a new long-range force may become necessary to explain the situation. Although Rothen's data has been confirmed by other investigators, there remains the possibility that various flaws in the inert blanket allow the antigen and antibody molecules to come into direct contact — holes or peaks and valleys — although work has been done toward disproving these hypotheses.

The antigen-antibody experiments have shown that the amount of antibody deposited depends upon the thickness of the blanket and not to any great extent upon its composition, although a metal coating, such as gold, over the antigen layer will stop the action when quite thin comparatively.

The orientation of the protein molecules in the antigen layer under the blanket and the number of layers (each one molecule thick) are also seen to determine the amount of antibody deposited; and give further insight to the mechanism of the action between these large protein molecules.

Radioactivity Unit Redefined . . .

With radioactive isotopes now an article of commerce, it has become necessary to standardize the units of radioactivity measurement. The familiar unit of radioactive disintegration, the curie, was defined originally as the amount of radon in equilibrium with one gram of pure radium and later extended to include any decay product of radium. Although this unit was recommended for use only in the radium family, it has been used outside those limits.

The rate of decomposition of one gram of radium has never been measured with accuracy greater than three per cent, but the National Bureau of Standards has arbitrarily set this quantity as 3.7×10^{10} disintegrations per second. In many cases it is convenient to use a smaller unit which is independent of natural constants. Consequently, the Bureau of Standards has recently designated as the rutherford (rd.) that amount of radioisotope which decomposes at the rate of one million disintegrations per second. On this scale, many radiotherapeutic doses will be around 100 rd., and tracer samples may be of the order of one rd.

Earth Time Inaccurate . . .

The rotation of the earth on its axis has been considered the prime standard for the measurement of time, but some doubts have now been raised as to its accuracy. Time studies made at the United States Naval Observatory have shown that the rotation of the earth may vary more than a second in four years. A statement issued by the superintendent at the observatory indicates that "Judged by the longitude of Mercury. . . the rate of rotation in 1929 was about one part in 20 million faster than it had been in 1909. Since 1929, the earth has appeared to slow down again, but only slightly."

Road Melts Snow . . .

A snow-melting highway has been opened for the first time on a public road, recently, on a 450-foot stretch of dangerous road near Klamath Falls, Oregon.

A ten-inch well, 390 feet deep, provides a natural source of heat from water which remains at about 190 degrees Fahrenheit. A pump sends water and antifreeze through a coil in this "natural boiler," heating the mixture to 160 degrees. In the pavement are imbedded 15,000 feet of three-quarter-inch wrought iron pipe made up into a grid for each of 15 30-foot road panels, which are separately connected to a two-inch main from the heating coil.

In this system the eight-inch slab of concrete is warmed to snow melting temperature. The pump is thermostatically controlled.

Reverberatory Furnace Operations

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Demonstrate High Temperature GAS Firing Technique

REVERBERATORY FURNACES designed to increase the production of zinc base die casting alloys have expanded melting and alloying capacity almost 50% over conventional pot melting. At Gerity-Michigan Corporation, Detroit, these Gas-fired furnaces operate on practically continuous schedules with savings of 35% to 40% based on time-saving methods and more efficient fuel utilization.

This application demonstrates the flexibility of GAS for industrial heating processes in high temperature ranges. But it also emphasizes the role of GAS in the development of production-line equipment for non-ferrous metals.

R. L. Wilcox, metallurgical engineer and Vice President of Gerity-Michigan Corporation describes the furnace and its application—"**This 18-ton Gas-fired reverberatory furnace has the advantage of extended service life, more efficient fuel utilization, closer temperature control, simplified alloy analysis.**"

Regardless of the type of heating operation or heat-treating process, GAS is the ideal fuel for any temperature requirement, or any production-line application. The characteristics of GAS—speed, flexibility, economy, controllability—are useful features for every industrial heating need. In view of rapid developments it's always worthwhile to keep your eye on what's new in Modern Gas Equipment.

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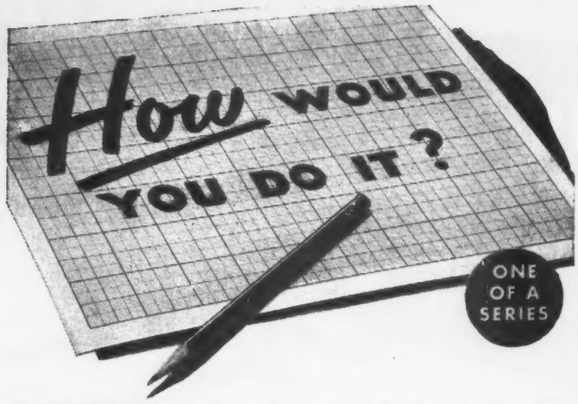

PROBLEM—You're designing a radio broadcast transmitter. The circuit includes condensers and other variable elements which must be adjusted by the operator. You want to place these elements for optimum circuit efficiency and where they will be easy to assembly, wire, and service. At the same time, you want to centralize the control knobs at a point convenient to the operator. How would you do it?

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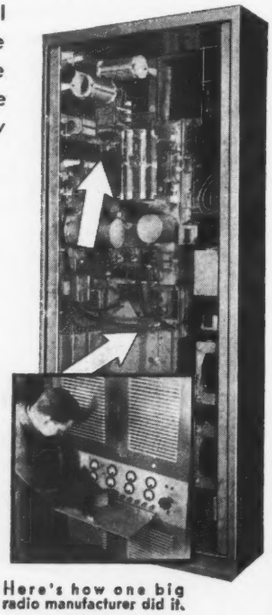

Here's how one big radio manufacturer did it.

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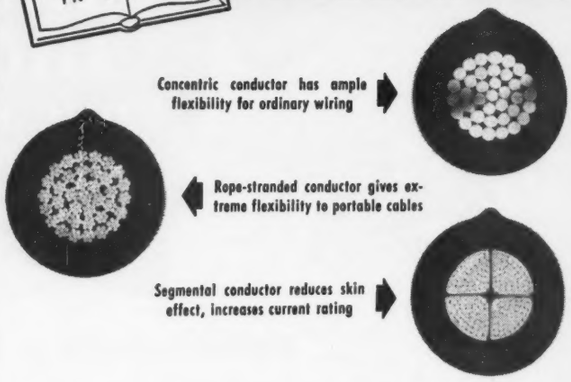
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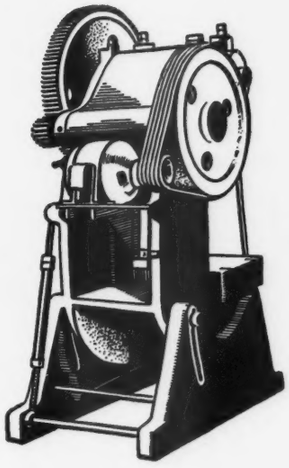
solution to can you do it

For every unique order in which the balls are pocketed, there is one corresponding reverse order in which the balls may be removed from the rack and placed back on the table. Since there is a one to one correspondence between all the orders of pocketing and all the reverse orders of removal from the rack, we will have our answer if we can determine all of the possible ways in which the balls may be put back in place from the rack.

Since the row of balls in the rack must never have an interior gap, our first choice is either one of the two end balls, one and fifteen; and, after one of these is removed, we are once again faced with a decision between the two new end balls. For the first fourteen balls, we always have two choices; and, for the last ball, there is only one possibility. This comes to a total of 2^{14} possible orders, from the stipulations of the problem.

Another page for **YOUR BEARING NOTEBOOK**



How to help a press keep punching

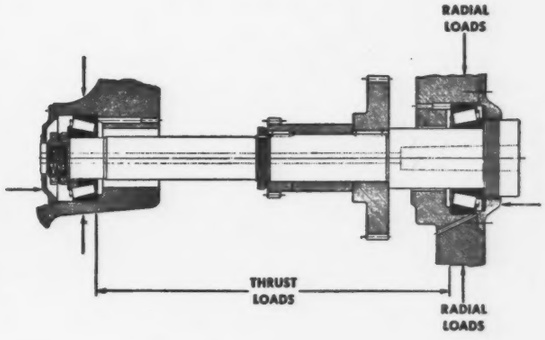
In a punch press, one of the engineering problems is to keep the flywheel and drive shaft in alignment and rotating freely in spite of terrific shock loads.

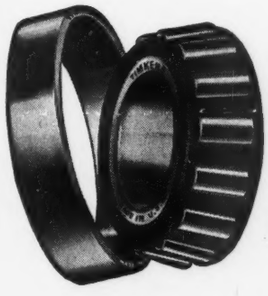
To solve this problem, engineers specify Timken® apered roller bearings.

Timken bearings hold the drive shaft and flywheel of a punch press rigidly in line. There's no deflection, wobble, or end-play. Friction and wear are negligible.

Why TIMKEN® bearings hold shafts in alignment

The line contact between rolls and races in a Timken bearing means wider, more rigid support for the shaft. Due to their tapered construction, Timken bearings carry radial and thrust loads in any combination, eliminating deflection and end-movement. And since wear in Timken bearings is negligible, shaft rigidity is retained for long years of service.





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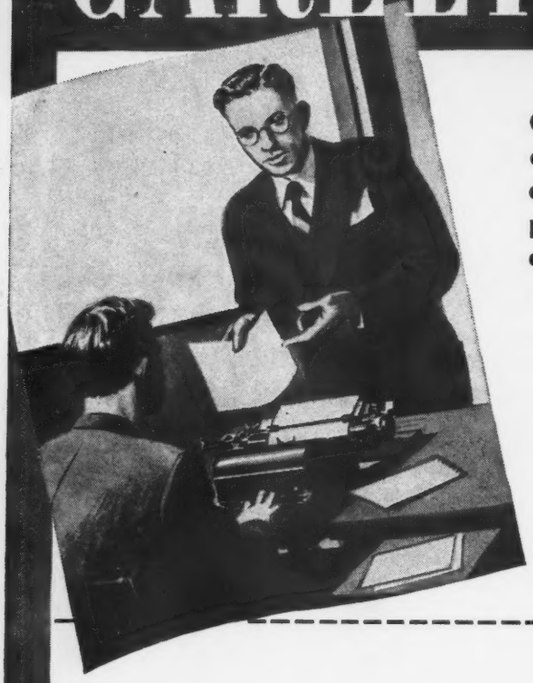
CAREERS AT GENERAL ELECTRIC



General Electric is not one business, but an organization of many businesses, offering opportunities in virtually all the professions. Here three G-E men brief the career-possibilities which the company offers to the student of advertising, the physicist, and the accountant.

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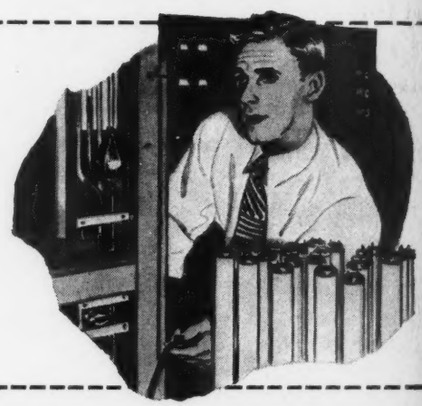

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